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A CORROSION FATIGUE/STRESS CORROSION TESTING FACILITY AT MATERIALS RESEARCH LABORATORY

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MATERIALS RESEARCH LABORATORY

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A Corrosion Fatigue/Stress Corrosion Testing Facility at Materials Research Laboratory

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and B.J. Baxter

MRL Technical Note
MRL-TN-568

Abstract

The mechanical testing facility at Materials Research Laboratory has been employed for conducting corrosion fatigue and stress-corrosion cracking investigations. In this note, attention is focussed on adapting two servo-hydraulic testing machines (MTS) for corrosion fatigue endurance tests on smooth specimens, and the development of an electro-mechanical testing rig for corrosion fatigue crack growth and stress-corrosion cracking tests on notched specimens. Emphasis is placed on specimen design and experimental techniques in conjunction with relatively inexpensive and simple command generation devices. The method of measuring crack growth is reported. Fracture mechanics relations for the determination of crack tip stress-intensity and critical material properties are described.

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Contents

Nomenclature

RATE 1	Selects load (RAMP) time in seconds.
RATE 2	Selects hold (DWELL) time in seconds.
BREAK POINT	Sets the load level at which the waveform changes direction, i.e. from RAMP to DWELL.
SPAN 1) SPAN 2)	Each independently sets the desired amplitude which is proportional to a certain percentage of the selected load range.
SET POINT	Sets a static offset load.
GAIN	Optimises the speed of the system response to a given DC error.
ΔK	Stress intensity range.
K_{ISCC}	A stress intensity threshold below which no stress-corrosion cracking occurs.
ΔK_{FAT}	Threshold stress intensity range below which fatigue crack growth is not observed.
K_{IC}	Plain-strain fracture toughness
da/dN	Crack growth rate under cyclic load.
da/dt	Crack growth rate under static load.

A Corrosion Fatigue and Stress Corrosion Testing Facility at Materials Research Laboratory

1. Introduction

The mechanical testing facility at Materials Research Laboratory is normally used for fracture toughness testing and general fatigue crack growth studies. Recently a need arose to extend the capability of this facility to cover corrosion fatigue and stress-corrosion cracking test programs. To accomplish these goals, two servo-hydraulic MTS machines were used to generate S-N data in both air and seawater environments. In addition, a horizontal test rig was commissioned to perform corrosion fatigue crack growth and static stress-corrosion cracking studies. This paper describes specimen design, the additions made to the standard MTS machines to perform the required tests, the principle of the operation of the horizontal test rig and the fracture mechanics test methods used in corrosion fatigue crack growth and stress-corrosion cracking studies.

2. Test Specimen Design

In fatigue testing programs, information or experimental data comprises S-N curves and fatigue crack growth rates. The specimen geometries used were of two different types, each suitable for one of the above set of data.

2.1 Smooth Un-notched Specimen

In corrosion fatigue testing, we have standardized a circular, waisted tensile specimen for the generation of S-N curves. Figure 1 shows the specimen design with built up shoulders at both ends, each of which accommodates an O-ring. The minimum diameter in the gauge section is 6.5 mm and the gauge section profile radius is 33 mm.

Final polishing of fatigue specimens is an important operation prior to fatigue testing. Consequently, a surface polish that removes ridges and grooves produced by previous machining and finishing operations, is necessary to reduce surface stress concentration effects on the fatigue properties. Also, a good surface polish facilitates microscopic surface examination of the fatigue damage although this does not hold true when surfaces are exposed to corrosive environments. In order to reduce the effects of surface stress concentration, the specimen test section was polished using 400, 800 and 1200 grade silicon carbide papers consecutively. This provided a smooth surface with the final polishing marks in the axial direction.

In corrosion fatigue investigations, only the specimen test section is exposed to a corrosive medium and in many cases the medium is circulated. In our investigations, an enclosure which envelops the specimen test section and provides complete sealing at both shoulder ends was used. Provisions in the form of inlet and outlet ports were made for circulating seawater as shown in Figure 2. A variable flow rate, electrically driven peristaltic pump was used to circulate seawater continuously.

2.2 Notched Specimen

Specimens for crack growth studies were of compact tension type, 12.5 mm thick, with a machined notch as shown in Figure 3. The specimen was loaded through clevises and loading pins. The same specimen design was used for both cyclic and static stress corrosion tests. In order to create sharp crack-like conditions prior to testing, the specimen was precracked by fatigue from the machined notch tip to an approximate depth equivalent to a starting a/W ratio of 0.4. The width (W) of the specimen was selected so as to provide measurable crack growth over a substantial length.

During the tests, most of the precracked length from the tip of the crack was submerged in the test solution. A clip gauge of the type described in ASTM Standard E 399-81 [1] was mounted on built-in knife edges across the specimen notch and the crack opening displacement, δ, was monitored. The description of the data acquisition system will be referred to a later section.

3. Experimental Techniques

3.1 Servo-Hydraulic Testing Machines

Two of these machines, Materials Testing Systems Inc., USA (MTS) Model 810, were used to generate S-N data on smooth specimens. A complete description of the operational and functional modes of these machines can be seen in MTS manuals for Model 810, one rated for 500 kN and the other for 250 kN static load capacity.

For the present requirements, the principal modification was centred upon the function generators of these machines as these were integrated with relatively inexpensive input and command initiation devices to perform the required waveform generation. Section

3.1.1 addresses the MTS 250 kN machine and this is followed by Section 3.1.2 on the MTS 500 kN machine.

3.1.1 MTS 250 kN Machine

(i) Trapezoidal Waveform

Figure 4a shows the control console housing the function generator of the machine which provides commonly used waveforms in fatigue testing. Of particular interest was the waveform which ramps (RATE 1) through zero and has equal hold periods (RATE 2) at maximum and minimum loads as shown in Figure 5a. Our initial requirement was to generate a similar waveform but without ramping through zero; in other words zero-to-tension with equal hold periods at zero and maximum-tension loads as shown in Figure 5b. Figure 6 illustrates how this was achieved. The output signal from the MTS function generator along with an offset voltage signal were added in an amplifier. The servo controller then receives the amplifier output signal and which is also the required waveform.

A RATE 1 value of 20 s is selected so that, in conjunction with SPAN 1 setting of 60 which corresponds to 30 kN on a 50 kN load range selection, it results in a loading rate of 1.5 kN/s. This provides a constant loading rate to achieve any tension load selected up to 30 kN. RATE 2 corresponds to the hold period and its selection varies with the BREAK POINT (or cut-off) load selected. For example, with a cyclic frequency of 0.0083 Hz (i.e. 0.5 cycles per minute) and a BREAK POINT load of 30 kN result in a RATE 2 setting of 40 s.

The selection of the BREAK POINT is carried out using a ten-turn (10 V) potentiometer. For example, to set a tension load of 25 kN, normally a setting of $10 \times 25/30 = 8.33$ V is required, but with the requirement of an offset, this value is halved to 4.17 V. Table 1 shows values of various parameters mentioned above for a range of cyclic loads, and using these one can initiate zero-to-tension trapezoidal waveforms with equal hold periods at maximum and zero loads. One of the essential features is that the commencement of each test occurs at a load which is half of the maximum test load and is half-way down the unloading portion of the waveform.

(ii) Modified Trapezoidal Waveform

Later in the corrosion fatigue test program, it was required to accelerate testing without affecting the loading rate and hold periods used in previous tests. In order to achieve this objective, it was decided to delete the hold period at zero load as this was considered a non-critical component of the overall waveform. For any maximum test load, it was necessary to vary the frequency in order to maintain previously achieved loading rate and hold periods.

This modified waveform can be programmed easily on the MTS 250 kN machine with the existing function generator. By setting RATE 1 to 20 s, a loading rate of 1.5 kN/s can be obtained. RATE 2 can then be set to similar values as mentioned in Table 1 previously, while the BREAK POINT setting will revert back to normal voltage, i.e. twice that mentioned in Table 1. Thus, the new set of values for different parameters as required to cycle with the above modified waveform are shown in Table 2.

Table 1 **Selected and Calculated Test Parameters to Generate a Cyclic Trapezoidal Waveform**

Maximum Load (kN)	RATE 1 (s)	RATE 2 (s)	BREAK POINT Setting (V), Half of Normal
20	20	46.67	3.33
21	20	46.00	3.50
22	20	45.33	3.67
23	20	44.67	3.83
24	20	44.00	4.00
25	20	43.33	4.17
26	20	42.67	4.33
27	20	42.00	4.50
28	20	41.33	4.67
29	20	40.67	4.83
30	20	40.00	5.00

Waveform	:	Trapezoidal
Loading/Unloading Rate	:	1.5 kN/s
Frequency	:	0.5 cpm

Table 2 **Selected and Calculated Test Parameters to Generate a Modified Trapezoidal Waveform**

Maximum Load (kN)	RATE 1 (s)	RATE 2 (s)	Frequency (Hz)	BREAK POINT Setting (V), Normal
20	20	46.67	0.0136	6.66
21	20	46.00	0.0135	7.00
22	20	45.33	0.0134	7.34
23	20	44.67	0.0133	7.66
24	20	44.00	0.0132	8.00
25	20	43.33	0.0130	8.34
26	20	42.67	0.0129	8.66
27	20	42.00	0.0128	9.00
28	20	41.33	0.0127	9.34
29	20	40.67	0.0126	9.66
30	20	40.00	0.0125	10.00

Waveform	:	Modified Trapezoidal
Loading/Unloading Rate	:	1.5 kN/s
Frequency	:	Varying

(iii) Composite Waveform

In later experiments this machine was utilised to generate S-N data using a secondary high frequency sinusoidal flutter superimposed on the low frequency trapezoidal waveform described previously. Once again, this composite waveform was not one of the waveforms obtainable from the existing function generator. Figure 7 is a block diagram showing how the required waveform was achieved.

It was recognised that the MTS control system can add input signals coming out of SPAN 1, SPAN 2 and SET POINT at a summing junction. The primary trapezoidal waveform can be fed easily through SPAN 1 and has been described previously. The secondary sinusoidal waveform from an external function generator was fed through SPAN 2. The frequency of this waveform can be pre-set on the external function generator while the amplitude is controlled by SPAN 2. The SET POINT control can now be used to offset the zero level in order to accommodate the secondary waveform at this level and thus prevent it from going negative.

To illustrate this procedure, consider the generation of the composite waveform with an amplitude of 20 kN for the primary trapezoidal waveform and ± 5 kN amplitude for the secondary sinusoidal waveform. By setting RATE 1 as 20 s and RATE 2 as $[60 - (20 \times 1.5)] = 30$ s, the frequency of the primary waveform is determined and it turns out to be 0.0136 Hz. SPAN 1 is set at 60 which on a load range of 50 kN allows a maximum attainable load of 30 kN. The amplitude of the primary waveform (20 kN) is selected using the BREAK POINT control on a scale of 10 V = 30 kN, i.e. a value of 6.67 V.

The next step is to provide an offset equivalent to the amplitude of the secondary waveform, i.e. ± 5 kN. This causes the primary waveform to operate between $P_{min} = 5$ kN and $P_{max} = 25$ kN although still maintaining its amplitude at 20 kN.

The frequency of the secondary waveform is now selected on the external function generator as 30 Hz. Since the signal is fed through SPAN 2, SPAN 2 is slowly increased and set at a level of 10% (or 1 V), which on a load range again of 50 kN (or 10 V) produces a maximum amplitude of ± 5 kN. Figure 7 illustrates the input and output signals as described above.

3.1.2 MTS 500 kN Machine

(i) Trapezoidal Waveform

The function generator as part of the control console (Figure 4b) of the MTS 500 kN machine is not as versatile as the one described for the 250 kN machine, although it can still perform basic waveforms such as sine, triangular and square. There is no provision to initiate a trapezoidal waveform with the existing function generator. This limitation was overcome by a special purpose ramp function generator which modifies the existing tension-compression square waveform into a zero-to-tension trapezoidal waveform as shown in Figure 8. In addition, a variable voltage clamp (VVC) was inserted between the output from the special purpose ramp function generator and the MTS servo controller. This enables a set loading/unloading rate to be maintained whilst the maximum output voltage is varied. Thus, for fatigue cycling, SPAN 2 is set to 60 which corresponds to 60 kN on a 100 kN load range. For any test load, P_{max}, up to 60 kN, the output level of the ten-turn VVC was set according to the equation $10 (P_{max} - P_{min}) / 60$. In addition, the loading and unloading rates were set to

provide a constant rate of 1.5 kN/s. The cyclic frequency throughout was set to 0.0083 Hz (0.5 cycles per minute).

(ii) Modified Trapezoidal Waveform

Fatigue testing on the 500 kN machine required further alteration to the existing function generator in order to provide the above modified waveform. In this particular case a zero-to-tension triangular waveform output is fed through a variable voltage clamp similar to the one shown in Figure 8. The procedure to convert the triangular waveform to the required waveform will be described below with the aid of Figure 9. First, an operating maximum load, P_{max}, of the required waveform, ABCD, is selected. The ABC portion of the waveform is then required to complete in 60 s. Using the above two selections and the loading rate of 1.5 kN/s, the loading time AB' is calculated, i.e. $P_{max}/1.5$ s. Then the hold time, B'C', can be easily obtained using th tion $(60 - P_{max}/1.5)$ s. Now, since the unloading and loading rates are equal, the cycl ..equency is calculated according to the relation $1/(60 + P_{max}/1.5)$ Hz.

It is now necessary to see how the above set of selections can be accommodated into a triangular waveform which can be obtained easily as an output from the existing function generator. This signal is then fed into the variable voltage clamp to obtain the required waveform.

It is apparent from Figure 9 that by extending AB and DC portions of the waveform to a point E one can obtain a triangular shape waveform. The load level E of such a triangle is controlled by SPAN 2 of the existing function generator. In order to determine SPAN 2 load setting which will allow the load to reach level E, the time AO in Figure 9 is first determined. In Figure 9, the ordinate EO divides the triangle into halves and this allows the determination of the time to reach level E, i.e. AO = 1/2 (1/Frequency) seconds. Knowing the loading rate (1.5 kN/s), the load level at E is determined as (AO × 1.5) kN. This load level can now be set by SPAN 2 of the servo controller with the appropriate load range selection.

To illustrate this procedure, if a waveform of the type shown in Figure 9 is to be generated at an operating maximum load, P_{max}, of 25 kN, set the cyclic frequency, f, to 0.013 Hz. Set the SPAN 2 control to [1/2 (1/f) × 1.5] = 57.5 kN on a 0 to 100 kN load range. This triangular waveform is then fed into the variable voltage clamp to clamp at the 25 kN level and provides the required waveform. Table 3 in conjunction with Figure 9 lists values of different parameters as determined for various operating load levels.

In the authors' experience, it was found essential to optimise the system's response at the start of the test in order to obtain the desired output. This is accomplished by adjusting the GAIN setting and simultaneously observing the response on a cathode ray oscilloscope.

The whole program of testing on these MTS machines is carried out under automatic shutdown conditions and this is accomplished by pre-setting actuator position limits. Once the actuator position exceeds the set limits, the hydraulic power pack of the system shuts down.

Table 3 **Details of Selected and Calculated Test Parameters to Generate a Modified Trapezoidal Waveform as shown in Figure 9**

Clamp load, Pmax (kN)	Frequency (Hz)	Hold Period (s)	Time to Reach Point 'E' (s)	SPAN 2 Setting on 0-100 kN Range
20	0.0136	46.67	36.67	55.0
21	0.0135	46.00	37.00	55.5
22	0.0134	45.33	37.33	56.0
23	0.0133	44.67	37.67	56.5
24	0.0132	44.00	38.00	57.0
25	0.0130	43.33	38.46	57.5

Waveform	:	Modified Trapezoidal
Loading/Unloading Rate	:	1.5 kN/s
Frequency	:	Varying

3.2 Electro-Mechanical Testing Rig

This rig, a modification of R.N. Parkins (University of Newcastle upon Tyne) design of a flat bed SCC machine, has a stiff two-column load frame in a horizontal plane. It is rated for zero-to-tension 22 kN load capacity and was built at Materials Research Laboratory using electronic components available commercially. Figure 10 shows the test rig with its driving motor which couples with a gear box at one end of the rig. At the other end, two proving rings mounted with strain gages act as a load cell. An electrical output signal proportional to the load is produced and is calibrated as 0.1 V/kN.

The control console, where the electrical circuitry is housed, operates the rig in both the automatic and manual modes. The automatic mode is used to perform both the cyclic and static tests, the operating procedure of each being described in the following sections.

The manual mode of operation is used for installing the specimen in the clevis and for making unloading-compliance measurements. This mode has the capability of independently driving the motor in forward and reverse directions.

The top part of the control console displays three meters in a row (Fig. 10). The first two from the left are used to pre-set maximum and minimum loads. The third one displays the instantaneous load during each cycle. The cyclic waveform function generator consists of a ramp rate controller and two timers as shown in Figure 10.

Before the beginning of each test, whether cyclic or static, two important safety precautions were taken. One was to protect the proving rings from sudden load impact due to specimen failure. A hexagonal nut is provided and the spacing between it and the proving rings support block is so adjusted that in case of specimen failure the nut forces against the block. This serves to restrain the loading rod from impacting into the proving rings. The other precaution was to provide position limit switches on either side of the crosshead situated on the motor drive end of the rig. These switches serve to stop the motor running away in

case the specimen fails. The motor drive shaft is protected from friction failure by lubrication.

3.2.1 Cyclic Test

The automatic mode is used to perform cyclic tests between independently set minimum and maximum loads. The generation of a trapezoidal waveform with equal hold periods at minimum and maximum loads is accomplished by setting a ten-turn ramp rate control potentiometer in conjunction with two timers, Figure 10, whose working range is selected as 15-150 s. Each timer is independently responsible for one half cycle, that is, time to load or unload plus the hold time. For example, to generate a trapezoidal waveform between 0 to 15 kN load range, the loading/unloading rate is set to give a rate of 1.5 kN/s. This loading or unloading time comes out of the selected half cycle periods on the respective timers. Therefore on a 60 s half cycle period, the loading/unloading time will be 10 s and the hold periods will be of 50 s duration.

As with the MTS machines, it was found desirable to delete the hold period at zero load in order to speed up testing. This was achieved easily by selecting the second half cycle period to a value just equal to the unloading time. In practice, the above procedure works very well for loading/unloading time periods greater than 15 s as this is the minimum value one can select on the timers. Nevertheless, a hold period close to zero seconds can still be achieved for periods less than 15 s.

A cyclic counter was designed to count each load cycle. It uses the amplified output from the proving rings (load cell) and with the aid of a level detector produces a pulse to the counter and records each cycle. The pulse is generated when the load increases past a threshold load point which can be pre-set on a 10-turn potentiometer (1 turn = 1 kN) at the beginning of each test.

3.2.2 Static Test

By means of a changeover switch the rig can be converted to static mode for static stress-corrosion testing. Again the automatic mode capability is utilised. In practice, a load level is pre-set before the start of the test and at start, the motor loads up the specimen to the demanded load level at a rate set on the ramp rate controller and holds it until fracture of the specimen. This results in increasing crack tip stress intensity with increase in crack length.

4. Approach to Measurements and Calculations

In essence, two approaches were taken. One was to determine S-N curves and the other to obtain crack growth rate information. Normally, the S-N data is obtained using smooth un-notched specimens, whereas specimens with a measurable crack length are used for crack growth rate studies. For these reasons attention is focussed on parameters such as load, stress, crack tip stress intensity, crack extension, number of cycles and time to failure. All the fatigue tests were conducted in constant-amplitude cycling with the machines functioning in load control mode.

4.1 Fatigue Life

Cycles for fatigue failure can be determined from smooth un-notched specimens and the results presented in the form of S-N curves, Figure 11. The overall fatigue life is made up of cycles for crack initiation and cycles for crack propagation. In load-control testing mode when the peak cyclic stress exceeds the yield stress of the material, a major portion of the total fatigue life is spent in crack initiation. This is because, when fatigue crack initiation occurs, the load bearing cross-sectional area decreases and the effective local stress increases rapidly leading to the point of instability. Thus, fatigue crack growth is limited. The result of such a fatigue failure can be clearly seen on the fracture surface where there will be a very small crack initiation region corresponding to most of the total fatigue life, and accompanied by a large overload region which may consume only a single cycle. In our experience, such a test can be programmed to terminate almost immediately following crack initiation, thus determining its exact location. This can be accomplished by pre-setting the position limits of the machine's actuator to within close tolerance. Normally, some finite crack opening and localised displacement occur before the machine shut-off.

In situations when the peak cyclic stress is below the yield stress and cycling is still in load-control mode, cycles spent in crack propagation increase and make up some portion of the total fatigue life. This is due to the fact that at low peak stress the point of instability, as described above, is reached much less rapidly. Evidence of this is again obvious on the fracture surface where the region of crack initiation is followed by region of crack propagation commonly characterised by fatigue striations.

There are strong indications that environmental effects cause the lowering of the S-N curves, and hence, reduce fatigue life. To verify this, future tests are planned both in air and seawater. Fracture surface examination will be carried out under scanning electron microscopy (SEM) to locate crack initiation points and an attempt will be made to estimate what percentage of total life is spent in crack initiation and crack propagation. The results from the above studies will be reported in a forthcoming paper.

4.2 Crack Growth Rate

The approach taken here was to monitor extension of a measurable crack with time or number of load cycles. The crack extension data is normally recorded as da/dn vs ΔK or da/dt vs ΔK and hence provides a quantitative measure of the material's resistance to fatigue or static stress-corrosion cracking respectively. Schematically, both curves look similar as shown in Figure 12. The da/dt vs ΔK curve (SCC) is divided into three regions, whereas, only the linear portion of da/dN vs ΔK curve (FAT) which is governed by the Paris equation, $da/dN = A\,(\Delta K)^n$, is of practical significance. In this equation, A and n are constants, and on logarithmic coordinates, da/dn vs ΔK is a linear relationship with a slope equal to the value of the exponent n.

Two other parameters of practical significance are ΔK_{FAT} and K_{Iscc} threshold values applying to fatigue and stress-corrosion, respectively. As shown in Figure 12, each is estimated approximately from the lower end of the slow growth region.

An alternative approach to determine K_{Iscc} is to plot stress-intensity, K, vs time to failure, t_f, as shown in Figure 13. In such a case, the K_{Iscc} can be conveniently determined by observing at what initial K level no failure occurs after a long test duration, strictly 1000 h [2].

The authors have used the unloading-compliance method for determining crack extension and fracture mechanics relations to calculate the applied crack tip stress intensities. Knowing the difficulty in measuring crack extension on a microscopic scale, the method adopted throughout was the unloading-compliance. Compliance is defined by the inverse slope of the load-deflection curve measured for each crack extension. Experience has shown that this method had two important attributes in the present work. First, the whole crack front is involved and hence an average value of the crack length is obtained. Second, the difficulty of direct observation and measurement on the specimen surface is avoided.

The procedure adopted involves periodic partial unloading, and measuring the resulting crack opening displacement, δ, using a clip gauge mounted across the specimen notch. This δ value was monitored through a data acquisition system. The system consisted of a 20-channel amplifier receiving the clip gauge signal, an analog to digital converter and a printer programmed to print and record at fixed time intervals.

The most reliable compliance calibration for the compact tension specimen is that given by Saxena and Hudak [3]. This relation, valid for the range $0.2 \leq a/W \leq 0.975$, is used to determine a/W from compliance:

$$a/W = 1.00 - 4.67\,(A) + 18.46\,(A)^2 - 236.82\,(A)^3 + 1214.90\,(A)^4 - 2143.60\,(A)^5$$

where $A = 1 / [(BE\delta / P)^{1/2} + 1]$

and
W = specimen width
δ = crack opening displacement
B = specimen thickness
P = load
E = Young's modulus (Plane stress)

Using the crack length and the applied load, the stress intensity, K, at the crack tip was determined from the expression described by Srawley [4] and valid for $a/W \geq 0.2$

$$KBW^{1/2}/P = \frac{2 + a/W}{(1-a/W)^{3/2}}\,[(0.886 + 4.64\,(a/W) - 13.22\,(a/W)^2 + 14.72\,(a/W)^3 - 5.6\,(a/W)^4]$$

5. Summary

Corrosion fatigue and stress-corrosion tests were undertaken using servo-hydraulic and electro-mechanical testing systems. The specimen designs included a smooth (un-notched), waisted tensile specimen for corrosion fatigue life studies (S-N curves), and a pre-cracked CT specimen for corrosion fatigue and stress-corrosion crack growth rates.

Some of the experimental methods were based upon modification of the existing servo-hydraulic testing systems. Simple and relatively inexpensive command generation

devices were incorporated into the existing function generators to achieve the required machine functions.

The electro-mechanical testing rig was used to undertake crack growth rate studies. This rig was a modification of the Parkins stress corrosion machine, modified using commercially available components to perform cyclic operation.

Measurements of primary interest were applied stress, crack tip stress-intensity, K, da/dt, da/dN, and threshold values ΔK_{FAT} and K_{Iscc}. The unloading-compliance method is used to measure crack growth. Using these measurements, along with fracture mechanics relations, it is possible to determine crack tip stress intensities, and hence the above material characteristics can be determined.

6. References

1. *Standard test method for plain-strain fracture toughness of metallic materials*, ASTM Standard E 399-81.

2. McMahon, Jr., C.J. (1973). Environment-assisted fracture in engineering alloys Part 1 - monotonic loading. *Journal of Engineering Materials and Technology*, pp. 133-141.

3. Saxena, A. and Hudak, Jr., S.J. (1978). Review and extension of compliance information for common crack growth specimens. *International Journal of Fracture*, **14** (5), pp. 453-468.

4. Srawley, J.E. (1976). Wide range stress intensity factor expressions for ASTM Method E 399 standard fracture toughness specimens. *International Journal of Fracture*, **12**, pp. 475-476.

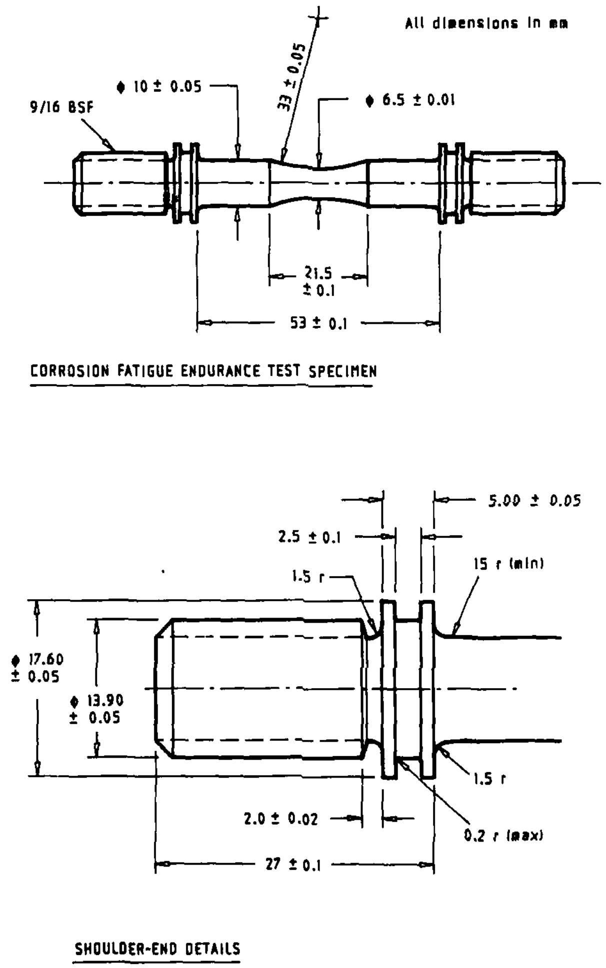

Figure 1 ***Dimensional details of the corrosion fatigue endurance (S-N) test specimen.***

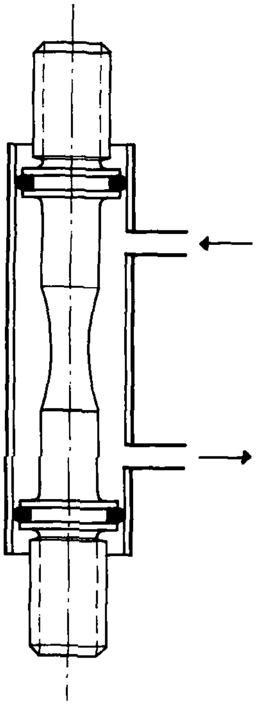

Figure 2 Fatigue specimen and the enclosure for circulating seawater.

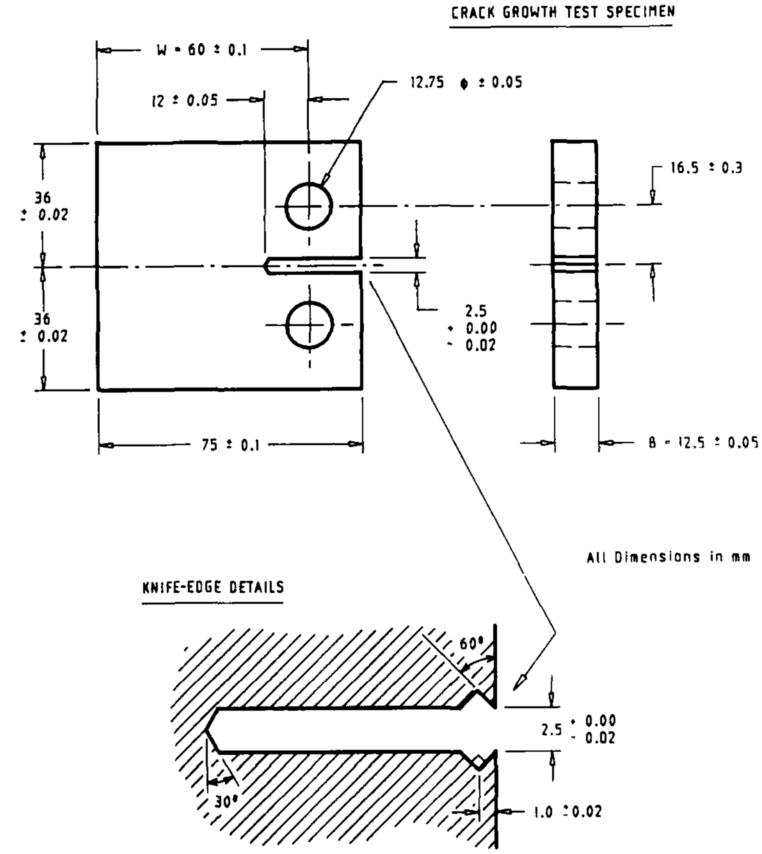

Figure 3 Compact tension type specimen for crack growth rate measurements.

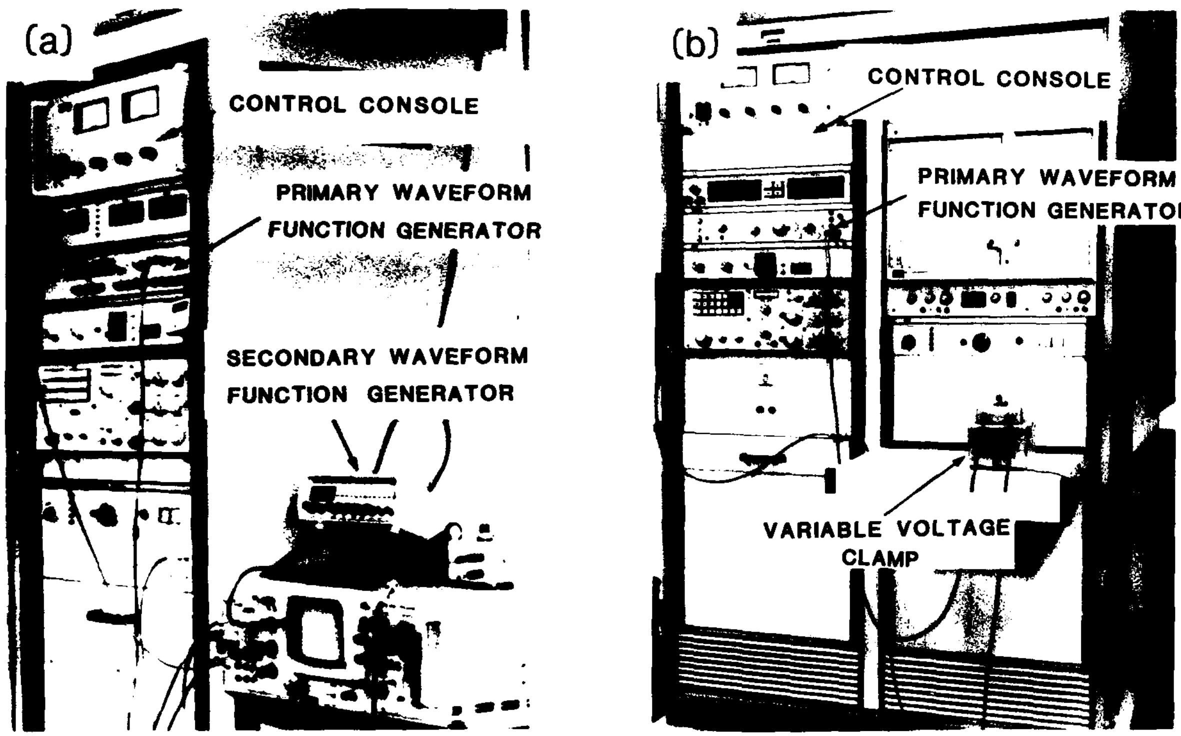

Figure 4 *Control consoles of (a) MTS 250 kN and (b) MTS 500 kN machines.*

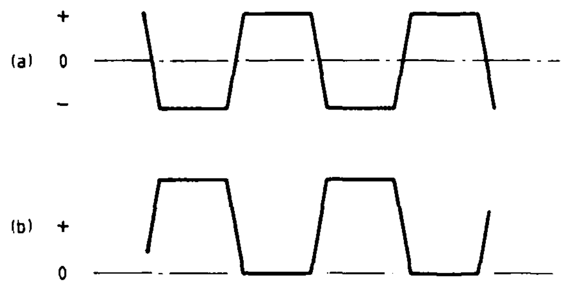

Figure 5 *Trapezoidal waveforms : (a) available from the existing function generator, (b) the required waveform.*

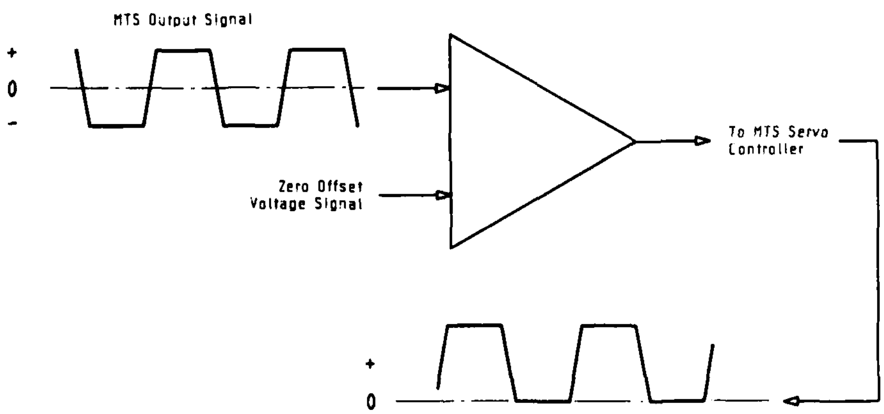

Figure 6 ***Block diagram showing modification of the tension/compression trapezoidal waveform on the MTS 250 kN capacity machine.***

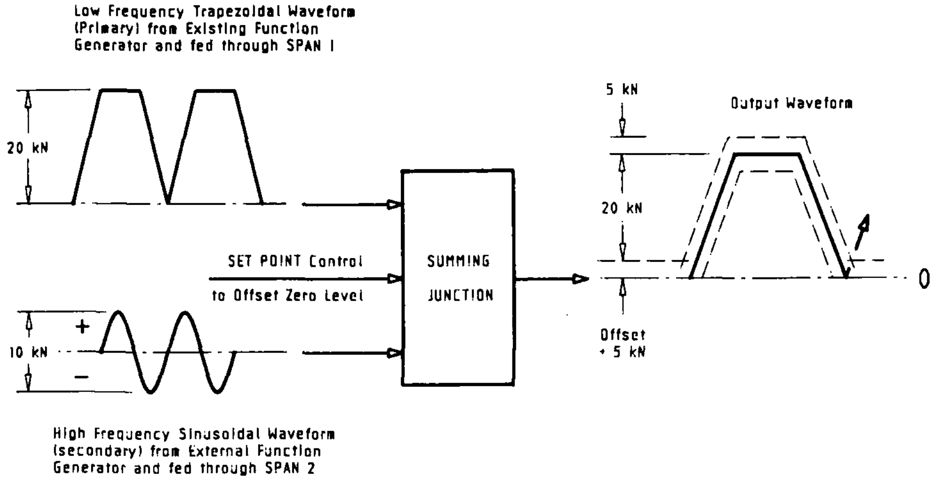

Figure 7 ***Block diagram illustrating input signals to a summing junction for the generation of a composite waveform on MTS 250 kN machine. The composite waveform is not drawn to scale.***

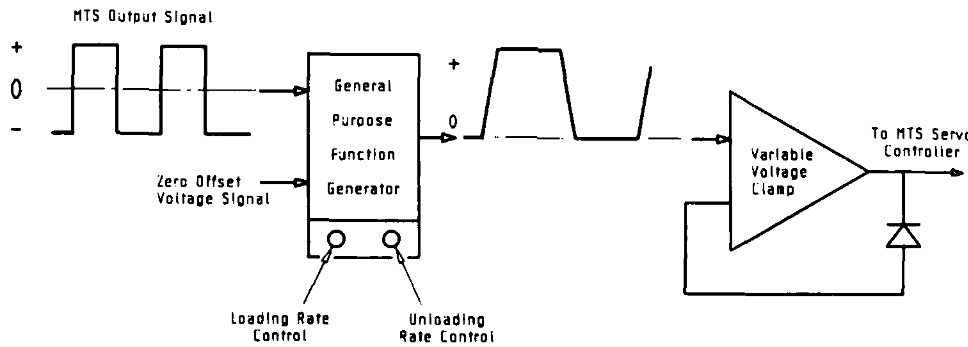

Figure 8 ***Block diagram showing modification of the tension/compression square waveform on the MTS 500 kN capacity machine.***

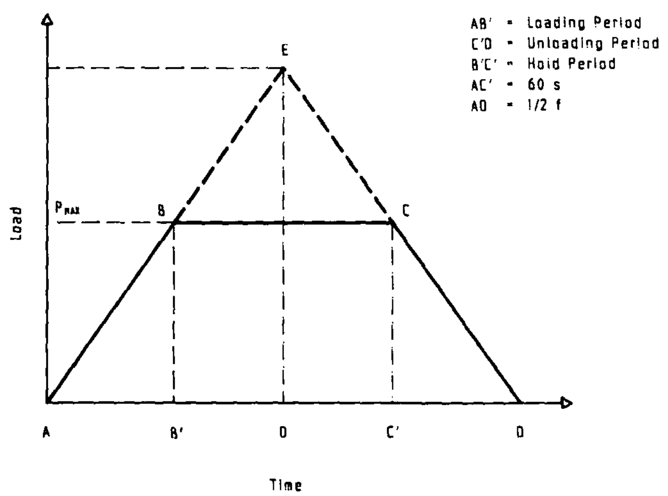

Figure 9 The required waveform, ABCD, accommodated in a triangular waveform, AED.

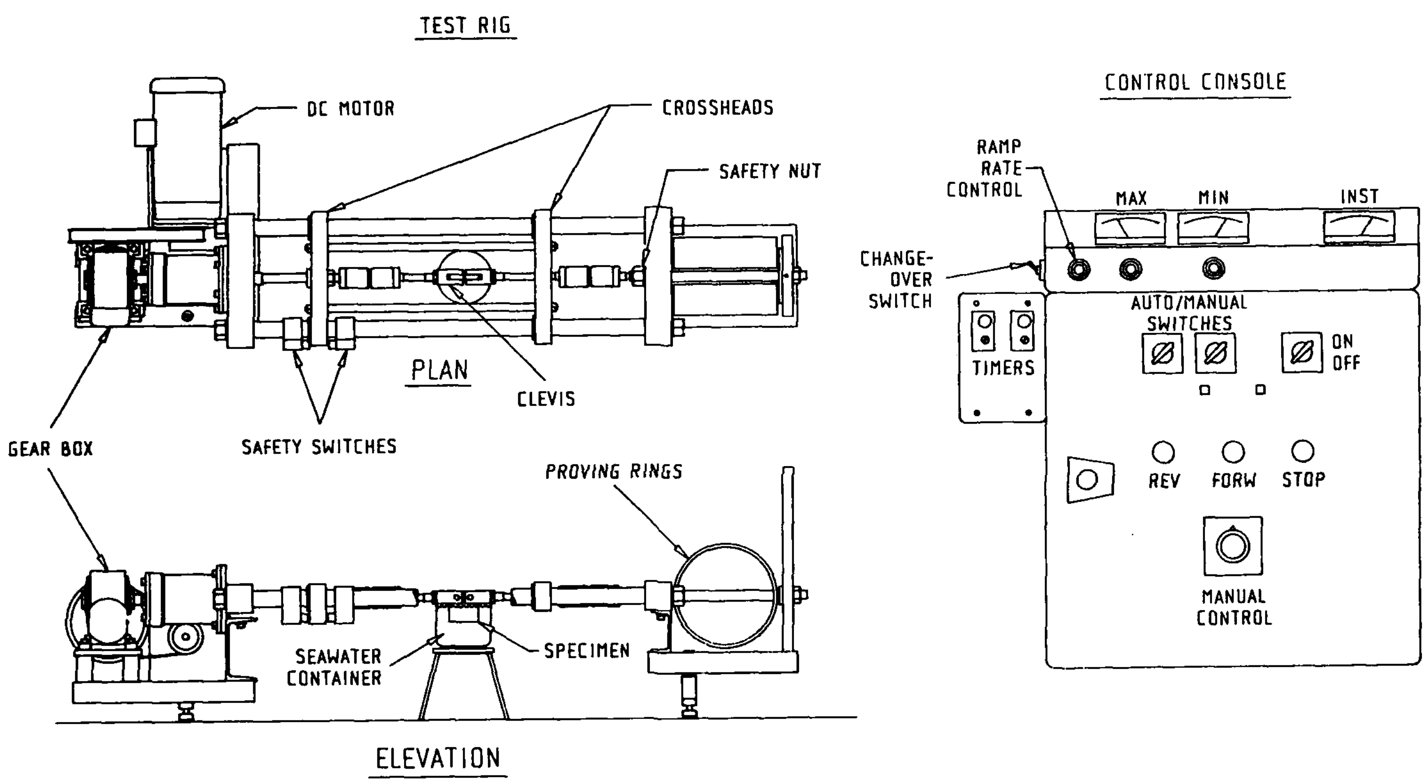

Figure 10 Plan and elevation views of the electro-mechanical test rig with its control unit.

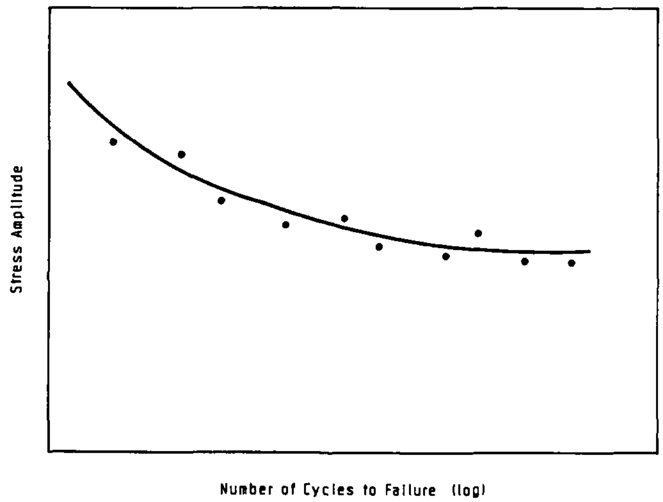

Figure 11 A representative S-N curve.

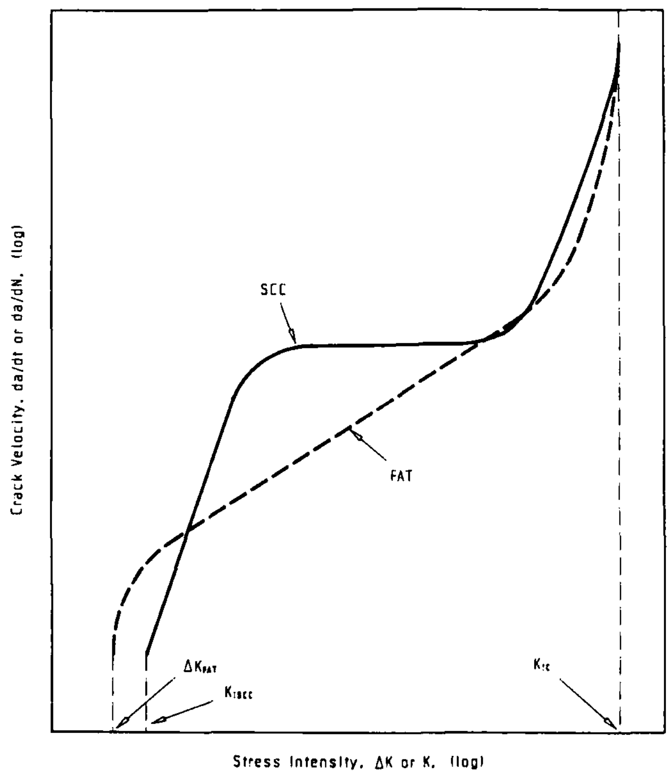

Figure 12 *Typical crack growth behaviour in cyclic fatigue (FAT) and static stress corrosion (SCC).*

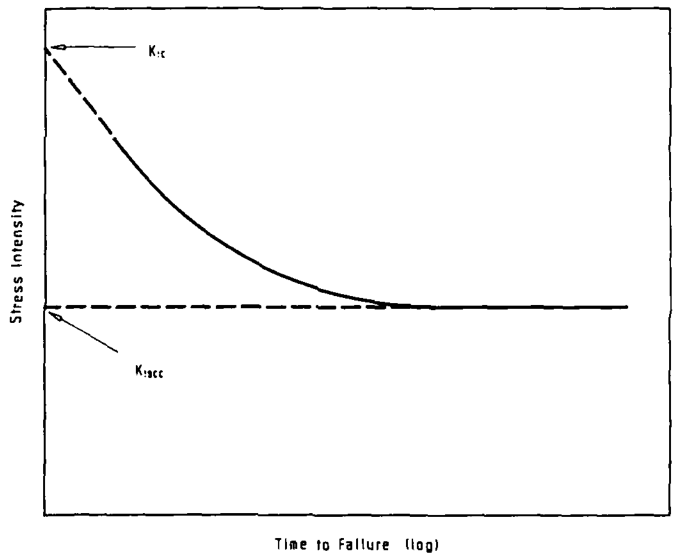

Figure 13 *A typical stress intensity versus time to failure curve for obtaining K_{Iscc}.*

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A corrosion fatigue/stress corrosion testing facility at Materials Research Laboratory

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ABSTRACT

The mechanical testing facility at Materials Research Laboratory has been employed for conducting corrosion fatigue and stress-corrosion cracking investigations. In this note, attention is focussed on adapting two servo-hydraulic testing machines (MTS) for corrosion fatigue endurance tests on smooth specimens, and the development of an electro-mechanical testing rig for corrosion fatigue crack growth and stress-corrosion cracking tests on notched specimens. Emphasis is placed on specimen design and experimental techniques in conjunction with relatively inexpensive and simple command generation devices. The method of measuring crack growth is reported. Fracture mechanics relations for the determination of crack tip stress-intensity and critical material properties are described.

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